US Army Corps
of Engineers
Hydrologic Engineering Center

Flood Mitigation Planning Using HEC-SAM

June 1980

Approved for Public Release. Distribution Unlimited.

TP-73

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to the Department of Defense, Executive Services and Communications Directorate (0704-0188). Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.
PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ORGANIZATION.

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
June 1980	Technical Paper	

4. TITLE AND SUBTITLE
Flood Mitigation Planning Using HEC-SAM

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Darryl W. Davis

5d. PROJECT NUMBER

5e. TASK NUMBER

5F. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
US Army Corps of Engineers
Institute for Water Resources
Hydrologic Engineering Center (HEC)
609 Second Street
Davis, CA 95616-4687

8. PERFORMING ORGANIZATION REPORT NUMBER
TP-73

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/ MONITOR'S ACRONYM(S)

11. SPONSOR/ MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
Presented at the Surveying and Mapping Division Specialty Conference, Denver, Colorado, June 1980

14. ABSTRACT
Flood control and floodplain management investigations using spatial data management techniques are increasing in the Corps of Engineers. Pilot studies initiated in the mid-1970's were successful in consolidating analysis concepts, fostering the development of spatial data file creation and management technology and enhancing the consideration of existing and alternative future development patterns in Corps' planning studies. Over thirty studies using HEC-SAM, the Corps' spatial data management system, are now completed or underway. HEC-SAM was created through selective acquisition of commercial software, adaptation of academic research products, and development by researchers at the Corps' Hydrologic Engineering Center (HEC) transfer agent. The evolution, present capabilities, and applications of HEC-SAM are described. Observations are offered on spatial technology development, implementation, and servicing.

15. SUBJECT TERMS
floodplain management, flood control planning, data management, spatial data management, geographic information systems, flood damage analysis, computer software management, urban hydrology

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
U	U	U	UU	24	19b. TELEPHONE NUMBER

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39-18

Flood Mitigation Planning Using HEC-SAM

June 1980

US Army Corps of Engineers
Institute for Water Resources
Hydrologic Engineering Center
609 Second Street
Davis, CA 95616

(530) 756-1104
(530) 756-8250 FAX
www.hec.usace.army.mil

TP-73

Papers in this series have resulted from technical activities of the Hydrologic Engineering Center. Versions of some of these have been published in technical journals or in conference proceedings. The purpose of this series is to make the information available for use in the Center's training program and for distribution with the Corps of Engineers.

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

The contents of this report are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products.

Flood Mitigation Planning Using HEC-SAM[1]

Darryl W. Davis, Member, ASCE[2]

ABSTRACT: Flood control and flood plain management investigations using spatial data management techniques are increasing in the Corps of Engineers. Pilot studies initiated in the mid-1970's were successful in consolidating analysis concepts, fostering the development of spatial data file creation and management technology and enhancing the consideration of existing and alternative future development patterns in Corps' planning studies. Over 30 studies using HEC-SAM, the Corps' spatial data management system, are now completed or underway. HEC-SAM was created through selective acquisition of commercial software, adaption of academic research products, and development by researchers at the Corps' Hydrologic Engineering Center (HEC). The HEC role continues to be that of system developer and technology transfer agent. The evolution, present capabilities, and applications of HEC-SAM are described. Observations are offered on spatial technology development, implementation, and servicing.

SPATIAL DATA MANAGEMENT SYSTEM

Overview

The HEC-SAM system was initially created to provide an analytical tool and analysis structure that would permit district offices of the Corps of Engineers to provide comprehensive planning assistance to local governmental units in decisions related to flood plain management (1). It has evolved into a general purpose spatial data file focused procedure with applications in more traditional planning studies in coastal regions as well as river basins. Elements of technical analysis provide the capability to assess hydrologic, flood damage, and environmental consequences of development situations reflected by alternative land use patterns and water management works, perform wildlife habitat evaluations such as the U. S. Fish and Wildlife Habitat Evaluation Procedure, perform boolean and overlay analysis, and produce a variety of computer graphics. The planning environment which the system is designed to service encompasses the present mission areas of the Corps with special focus on urban areas.

The general analytical strategy that comprises HEC-SAM is to: a) assemble and catalog basic geographic and resource information into a

---

[1]Presented at the June 1980 Surveying and Mapping Division Specialty Conference, Denver, Colorado.

[2]Chief, Planning Analysis Branch, The Hydrologic Engineering Center, Corps of Engineers, Davis, California 95616.

computer data bank, b) forecast and place into the data bank selected alternative future development patterns, formulate an array of management alternatives, c) perform comprehensive assessments of the development scenarios of interest, and d) recycle for additional alternatives.

The system has emerged from the pilot study stage where it was successfully applied in several studies of the type for which it was created. The pilot studies have proved HEC-SAM to be sufficiently attractive and powerful enough for traditional Corps' survey investigations to make use of major portions of the technology in their studies.

System Characteristics

Software. The HEC-SAM system is comprised of a family of data management and analysis computer programs. Figures 1A and 1B present a functional flow diagram of the data management, analysis, and output of HEC-SAM. The solid lines indicate file transfers that are automated and the dashed lines file transfers that are presently under development. The capped labels in the boxes are titles of individual computer programs.

The system has three distinct functional elements: Data File Management, Data File Processing Interface, and Comprehensive Analysis. The computer programs comprising each of these functional elements are briefly described in Table 1. The data file management element is comprised of the subfamily of computer programs required to process raw map or other type data to the grid cell format of the general data bank. The Data File Processing Interface element is comprised of computer programs that compile and reformat grid data retrieved from the data bank into a form processable by the general analysis computer programs.

TABLE 1

HEC-SAM Software Summary[1/]

Data File Management	Description
AUTOMAP II (ESRI)	Prints grey shade overprint maps and generates grid data from polygon data.
BANK (HEC)	Creates and manage files comprising grid cell data bank.
4 VIEW (WES)	Provides plots of perspective views of grid data.
GRDPLT (ESRI)	Provides pen plots of grid data.
GRIPS (ESRI)	Transforms polygon data into grid cell format and enters it into the data bank.
PLYPLT (ESRI)	Provides pen plots of data variables that are in polygon format.

1/ Parenthesis notation indicates origin--HEC (The Hydrologic Engineering Center) WES (Corps' Waterways Experiment Station, ESRI (Environmental Systems Research Institute). The asterisk signifies generalized HEC program.

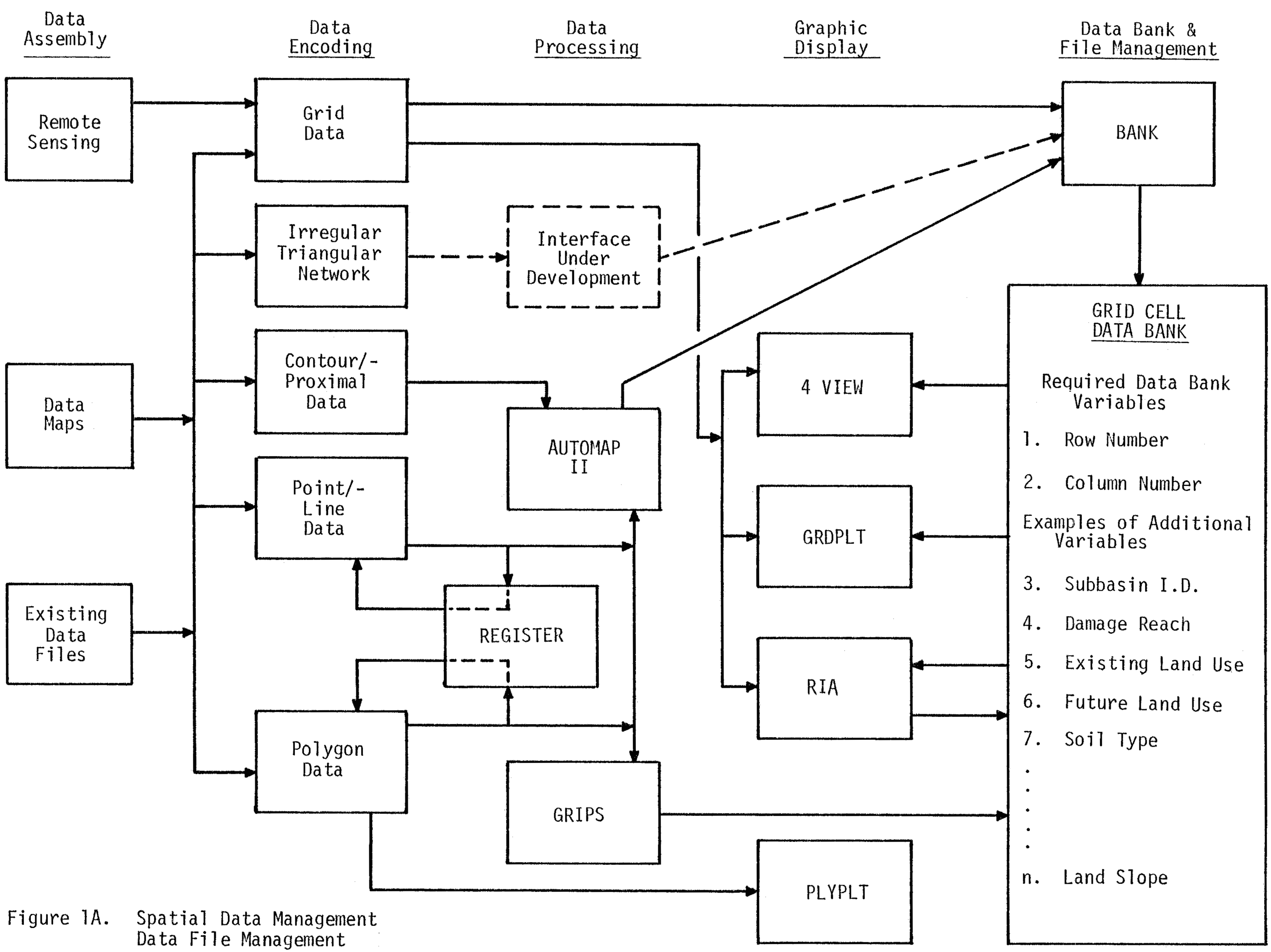

Figure 1A. Spatial Data Management Data File Management

Dav's

Figure 1B. Spatial Data Management Data File Processing Interface and Comprehensive Analysis

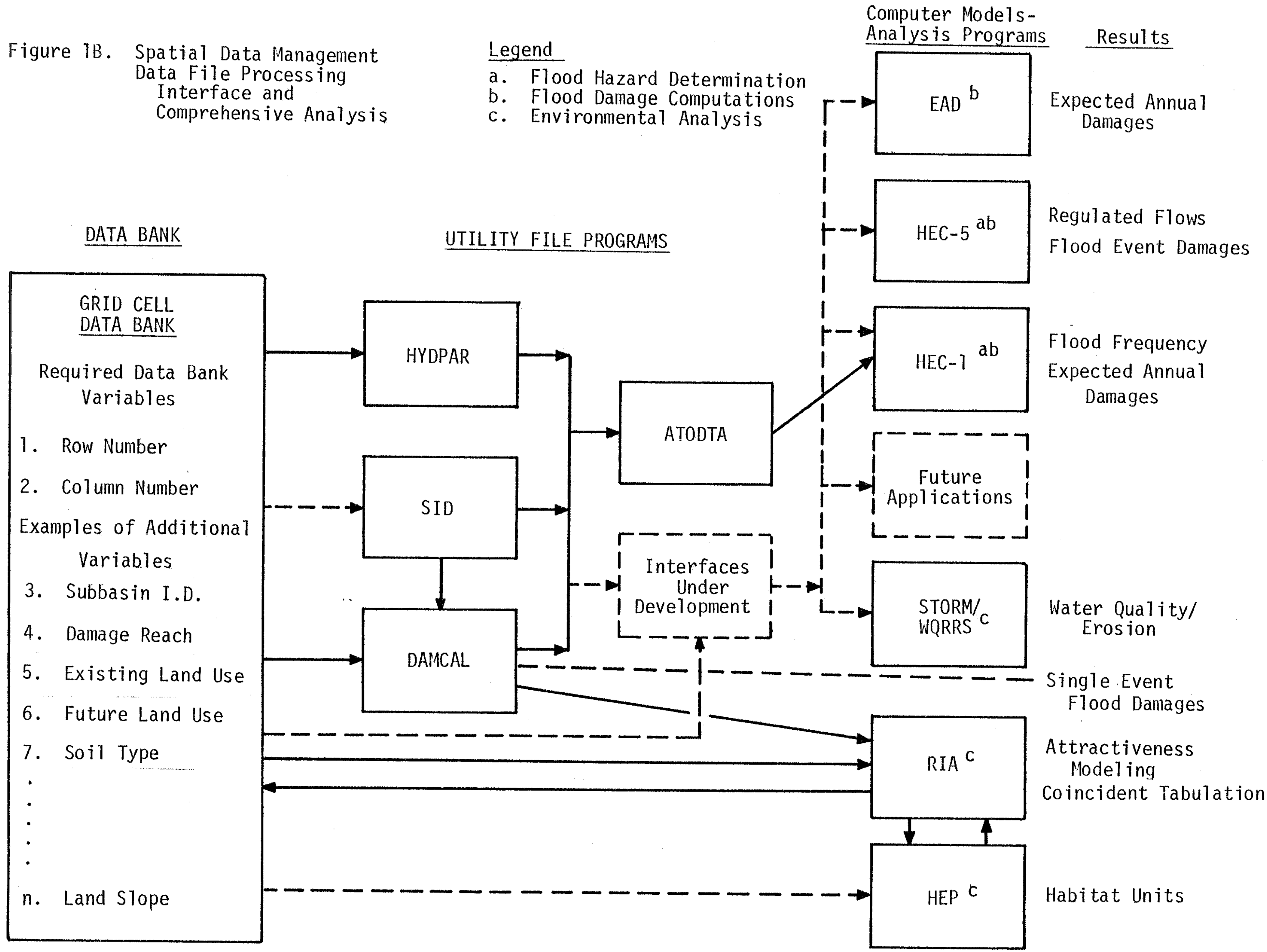

TABLE 1 Continued

REGISTER (HEC)	Registers coordinate system of polygon data sets to adopted coordinate system.
RIA (HEC)	Provides line printer grey shade overprint maps of grid data.
<u>Data File Processing Interface</u>	
ATODTA (HEC)	Coordinates and manages economic, hydraulic, and hydrologic data for input to HEC-1.
DAMCAL (HEC)	Generates elevation-damage data files from grid data.
HYDPAR (HEC)	Generates hydrologic, storm quality, and erosion modeling parameters from grid data.
SID (HEC)	Generates elevation-damage data files from individual structure data.
<u>Comprehensive Analysis</u>	
HEC-1 (HEC*)	Rainfall runoff and flood damage model.
HEC-5 (HEC*)	Reservoir system for flood control and conservation model.
EAD (HEC*)	Expected annual flood damage computation program.
RIA (HEC)	Resource analysis program performing distance determinations, graphics and attractiveness analysis.
STORM (HEC)	Urban storm water quality and surface erosion model.
WQRRS (HEC)	Stream water quality simulation model.
HEP (HEC)	U. S. Fish and Wildlife Service Habitat Evaluation Procedure program.

The Comprehensive Analysis element is comprised of the generalized computer programs that perform detailed technical assessments using the linked input data files. These computer programs are standard tools used within the Corps that have been modified to accept data file input as an alternative to the usual card input and, in a few instances, modified to encourage increased systematic analysis to take advantage of access to a comprehensive data bank.

<u>Hardware</u>.

The HEC-SAM system basically operates on major computer systems. The system used during original program development was a major CDC 7600 installation. The programs are written in ANSI Standard FORTRAN IV and are portable between major computer systems. The programs are maintained for access by users on the LBC system in Berkeley, California, and on the Boeing Computer Services System, also a CDC installation. The Data File Management and Data File Processing Interface programs do not require the storage and computer speed of the major programs and thus could be easily operated on minicomputer systems. The comprehensive analysis programs presently require the core size and execution speed of major computer systems to be used efficiently and effectively.

Input, Analysis and Output. The system envisions that the basic spatial data that is normally used in map form during planning studies would be processed into a spatial data file by application of the various Data File Management programs. The specific programs used would depend upon the form of the digitized data, e.g., point, grid, contour or polygon, remotely sensed (classified LANDSAT), or existing computer files. Analysis is performed for a selected condition, (e.g., a projected land use pattern with a certain flood hazard zoning policy or project) by processing the proposal into the data bank as a new (or modified) variable and successively executing the Interface and Comprehensive Analysis programs. The program executions would be dependent upon the proposal that is under investigation.

The analysis programs require specific input data (external from the data bank) such as the hydrologic topology of the study area, stream geometry, precipitation, relationship between land use and runoff, damage potential, etc. The initial modeling calibration data is prepared conventionally, based on observed data supplemented by parameters generated from the data bank and then the calibration data is used as the mechanism for forecasting the change in modeling parameters that would result from changed conditions or proposals.

The output includes: a) grid map graphic displays of the data variables, and results of attractiveness and impact analysis; and b) detailed numeric printout of runoff hydrographs, flow exceedance frequency relationships, expected annual damage, storm pollutographs, wildlife habitat unit values with and without proposals, and time traces of erosion and a range of water quality parameters for existing and selected alternative future development patterns. The output corresponds to the complete range of technical output of comprehensive flood plain assessments. Higher quality graphics can be generated from grid and polygon files if desired.

Resolution and Accuracy. A major purpose in creation of HEC-SAM was to cause consistent, systematic analysis of future development to be performed in traditional functional areas (and to a great extent using traditional analysis concepts and tools) with a common data set. The level of detail and accuracy of final analysis was to be consistent with traditional methods The cell size for the data base has the dominant influence on the resultant level of output detail. Hydrologic computations can comfortably use rather coarse grid sizes (4 to 10 hectares) and relatively few categories of major variables (for example 4 to 5 land use classes). Environmental analysis does not seem to be more greatly demanding in detail of data resolution than required for hydrologic analysis, although some habitat analysis may require as many as 15 or more cover types to be separately encoded for the natural areas. Flood damage calculations require accurate terrain resolution within the flood plain and quite extensive land use categorization (upwards of 20 classes). Grid cells as small as 1/8 hectare have been used in sharply breaking topography, whereas, in more gentle terrain, cells of 2 hectares were acceptable. In the flood plain area, the terrain variation resolution requirements for flood damage analysis dictates the appropriate grid cell size. The present state of HEC-SAM does not permit variable grid cell size being simultaneously stored in the data banks so that, generally, the terrain in the flood plain of the study area dictates the size of the grid cells for all data variables. Many studies have constructed two data banks--a coarse grid file covering the entire study area that is used for basin-wide analysis and a fine grid file that is used for detailed flood plain studies. Activity is underway (Figure 1A) to include the variable resolution (as well as terrain modeling advantages) of irregular triangular grid structure in the HEC-SAM system.

Analysis Capabilities

The general capability of HEC-SAM is to provide a comprehensive systematic, assessment of alternative development patterns and flood mitigation plans in the functional areas of flood hazard, flood damage and environmental status. A listing of the more commonly used capabilities in each of these areas would include:

Flood Hazard. HEC-SAM will evaluate the following prespecified alternatives for a specific storm event (such as the 100-year exceedance interval event) or a range of storm events (development of flow and/or elevation exceedance frequency relationship) at any or all selected important locations within a study area.

- Changed land use patterns
- Changed drainage system
- Flood plain occupancy encroachments
- On-site water management strategies
- Engineering works of levees, channel modifications, reservoir storage and flow rerouting
- Water management practices

Flood Damage. HEC-SAM will evaluate the dollar damages for a specific event (such as the 100-year exceedance interval event) and the expected value of annual damages for each designated location in the study area and each damage category (residential, commercial, etc.) for the following:

- Changed flood plain occupancy
- Changed watershed runoff such as from changed land use
- Changed stream conveyance such as from flood plain encroachment
- Changed structural construction practices
- Alternative development control policies
- Changed value of flood plain structures
- Modified structure damage potential such as from floodproofing
- Effects of engineering flood control and drainage works of levees, channels, reservoirs, and diversions

Environmental. HEC-SAM will perform a variety of environmental evaluations for the alternatives and conditions described in Flood Damage above. The evaluations that can be performed are:

- Forecast changes in habitat units by wildlife species and the ecosystem
- Catalog environmental habitat changes from changed land use (coincident analysis)
- Forecast changes in land surface erosion and transport for land use and engineering works changes
- Forecast changes in runoff quality from changed land use
- Forecast changes in stream water quality
- Develop first order attractiveness and impact spatial displays
- Identify enriched habitat zones by ecotone analysis

PROJECT APPLICATIONS

HEC-SAM was developed to service a series of pilot studies which were designed to test the basic concepts of a broadened community service's oriented type of investigation which was under study by Corps' management. The studies are referred to as Expanded Flood Plain Information Studies (XFPI). The original pilot study (Oconee River Basin and several of a second generation of pilots are completed. These studies were designed to confirm concepts. A third generation of XFPI studies is nearing completion. These were undertaken to test the geographic transferability of the techniques. A group of Corps' regular planning studies using HEC-SAM have been initiated this past year. Publications are available describing the research efforts for the pilot studies (1), (3), (4), (5), documenting the initial pilot study findings and documenting completed field applications (6), (7), (8). Table 2 lists Corps' studies that involve substantial use of spatial data management techniques. The responsible field office of the Corps should be contacted for up-to-date information on the progress of the study.

Published results from the Trail Creek watershed pilot study are presented to illustrate the nature of the products which may be generated from HEC-SAM focused studies.

TABLE 2

APPLICATIONS OF

SPATIAL DATA MANAGEMENT TECHNIQUES

Study (Basin	Corps District	Status
XFPI's		
Oconee Basin	Savannah	Complete
Rowlett Creek	Ft. Worth	Complete
Boggy Creek	Jacksonville	Complete
Pennypack Creek	Philadelphia	FY 80 completion
Crow Creek	Rock Island	" " "
Wolf River	Memphis (WES)	" " "
Sonoma Creek	San Francisco	" " "
Sewickley Creek	Pittsburg	" " "
Walnut-Williamson Creeks	Ft. Worth	" " "
Willow Creek	Alaska	" " "

TABLE 2 Continued

Study (Basin)	Corps District	Status
Survey/Phase I Pilots		
Kissimmee Basin	Jacksonville	Underway
Walnut Creek	Ft. Worth	Underway
Conley Creek	Savannah	Initiated
Upper Clinton River	Detroit	Soon to begin
Tallaboa River	Jacksonville/San Juan	Initiated
Other Active Planning Studies		
Passaic Basin	New York	Well underway
Salt River	Los Angeles (Phoenix)	Underway
Ocean City	Baltimore	Advanced
Tucson	Los Angeles	Initiated
Harding/Cahokia	St. Louis	Underway
Upper Roanoke/Dan Basin	Wilmington	Completed
Morrison Creek	Sacramento	Initiated
Mississippi Sound	Mobile	Initiated
Raritan	New York	To begin soon
Delaware Basin	Philadelphia	To begin soon
Miscellaneous Completed		
San Francisco/San Pablo Bays	San Francisco	Completed
Upper Russian River	San Francisco	Completed
Lake Erie Waste Water Mgmt.	Buffalo	Completed
Santa Ana River Basin	Los Angeles	Completed

Trail Creek drains 12 square miles of the Oconee watershed and includes a portion of the city of Athens, Georgia, in its lower reaches. The test area at the time of study (1976) was about 10 percent urban and expected to grow to 20 to 30 percent urban by 1990. The data bank created for Trail Creek included 15 data variables at a grid cell size of 0.6 hectares (1.53 acres).

Flood Hazard

Table 3 displays selected results of evaluating the alternative conditions indicated. Note that the flow rate increase for each of the specified exceedance intervals is less in proportion for the rarer events. Note also that the flow rate change for the 100-year event is different between control points and that the change in flood elevation is not directly proportional to the change in flow. Study of the table indicates that the hydrologic consequences of land use changes are complex and require careful, professional analysis.

TABLE 3
HYDROLOGIC DATA SUMMARY
TRAIL CREEK TEST

100-YEAR PEAK FLOW AND ELEVATION

Index Station	Existing Land Use Flow (cfs)	Existing Land Use Elevation	1990 Land Use Flow (cfs)	1990 Land Use Elevation
1	7600	627.1	9300	628.3
3	2600	711.9	2900	712.2
5	1600	964.2	1650	964.3

FLOW--EXCEEDANCE INTERVAL DATA
(cfs)

Exceedance Interval (yr.)	Sta. 1 Exist	Sta. 1 1990	Sta. 3 Exist	Sta. 3 1990
5	2000	2800	800	960
10	3000	3900	1100	1300
25	4400	5600	1600	1850
50	5800	7300	2100	2350
100	7600	9400	2700	3000

Flood Damage

Table 4 summarizes the expected annual damage assessments for a range of hydrologic conditions and land use control policy sets for the three damage reaches within the Trail Creek watershed that sustains significant damages. The 1990 land use condition is a projection based on a local agency judgment.

TABLE 4

SELECTED DAMAGE ASSESSMENTS
TRAIL CREEK TEST
(Expected Annual Damage in 1000's $)

CODE	EVALUATION CONDITIONS LAND USE POLICY	HYDROLOGY	1	2	3	TOTAL
I	Existing	Existing (1974)	1.5	1.9	11.9	15.3
X	1990 with no development controls	1990	1033.3	350.0	37.7	1416.0
IV	1990 with new development at 1974 100-year flood level	1990	19.3	63.8	23.8	106.9
V	1990 w/new devel. @ 1974 100-year & floodproofed to ground floor	1990	16.8	18.9	4.7	40.4
VIII	1990 w/new devel. @ 1990 100-year & floodproof to ground floor	1990	11.9	16.0	2.8	30.7

The results may at first glance be difficult to understand. An initial reaction might be that the evaluation condition of placing new development at the existing 100-year flood (CODE IV) should be similar to the existing condtion (CODE I). The large increase in expected annual damages is caused by: a) damage occurring to the basements of new construction, b) the 100-year flood for the 1990 land use condition is higher than the 100-year flood for the existing land use condition, and c) damage still occurs to the new development from flood events that exceed the 100-year event. Several other evaluations that include a number of alternative management and floodproofing policies are included to demonstrate the broad capability of the spatial data management techniques as well as present some interesting evaluations.

The nonstructural flood plain management evaluations that may be accomplished using HEC-SAM are described in (4). A recent innovation has been directly interfacing the individual structure processing program (SID Figure 1B) with the spatial program (DAMCAL), thus permitting detailed assessment of individual unique structures while evaluating a given land use condition.

Environmental

The RIA Program has formed the central focus of environmental analsis. The RIA Program contains the traditional distance determination (centroid to centroid), impact assessment (five levels), attractiveness modeling, coincident tabulations, and computer line printer graphics (22 map levels). Processing is controlled by an executive routine that manages the intermediate data files in a manner that is transparent to the user.

A common application has been to use the coincident tabulation capability to tabulate acreages and percentages of the coincident of the classes of two data variables within the data classes of a third data variable. The third data variable is usually a boundary variable (census tract, township, watershed, damage reach). The coincident tabulation results are used as basic data for the construction of narrative impact scenarios based on the habitats lost from the change in land use pattern.

Other applications have included: a) identification and analysis of ecotone or habitat fringe areas, b) identification of habitat areas impacted by changes in flood elevation-frequency, c) generation of modeling parameters for quality and sediment-erosion analysis by the STORM program. A most recent application has been the computation of time history scenarios of wildlife habitat unit changes resulting from land use changes or management actions.

Computer Graphics

Computer graphics have been used extensively in several phases of the HEC-SAM focused studies. The primary uses have been for data verification during encoding activities, data bank variable verification, and graphic display analysis results. Table 1 briefly describes the graphic sofware currently supported by HEC (RIA, AUTOMAP II, GRDPLT, PLYPLT, 4-VIEW).

There is a heavy reliance on line printer graphics for working maps. Final report graphics are often pen plots but not always. Innovative use of color by creating separations made from successive line printer maps have proven to be quite acceptable. Studies that rely on line printer working maps should select grid cells that are proportioned to the size of a computer line printed character to avoid producing distorted printer maps. Common cell sizes have been either 1.15 or 1.53 acres (depending on printer spacing).

The pen plot programs use either a Calcomp plotter, a Textronix CRT, a microfilm or 35mm film. The creation of the final report graphics is most often accomplished by first executing the display on a Tektronix CRT to design the display, and the plot is disposed to the plotter or 35mm film. Some applications have used 35mm graphic outputs to create color separation plates for color printing.

TECHNOLOGY DEVELOPMENT, MANAGEMENT AND TRANSFER

Advanced computer technology development, implementation and servicing are the stock-in-trade of the Hydrologic Engineering Center. A method for successfully functioning in this arena has evolved over the years that generally operates as follows: a) needs for new methods and procedures surface through the Center's continual contacts with field offices, b) research and development work is performed (normally in the production environment) to solve a specific problem, c) the solution is generalized in both conceptual and geographical scope so that it may service other users, d) high quality documentation is developed and the technology readied for long term service and maintenance, e) training courses are held and consultation projects performed that gradually, but systematically, move the technology into the normal stream of work efforts in the Corps, and f) continuing development, servicing and maintenance is commenced to assure timely aid to all potential users and to guarantee that up-to-date capabilities are continually incorporated.

Observations for Systems Developers or Users Contacts

Several "truisms" based on HEC's experience have emerged that are applicable to the development and implementation of spatial data management systems. These comments are most applicable to the organizational unit or level in an institution (public or private) who are either developing new systems themselves or will be the user contact point within an organization that is charged with providing service to in-house or other users.

a) Large scale, complex, comprehensive computer programs and systems of programs are dynamic entities that require continuous nurturing and support in order to remain viable and useful. Such computer software needs a permanent home; an institution that is philosophically committed to the improvement in procedures, morally committed to servicing and improving the computer programs, competently staffed to perform the task, and available on call to users.

b) Business-like computer program code generation and its subsequent management is vital for the software to be portable between computer systems. As a general guide, use of special purpose languages that are proprietary or not generally supported by major computer installations should be avoided. Adherence to ANSI (American National Standards Institue) standards is important and modern modular programming practice with avoidance of machine or language dependent routines will greatly reduce computer source code maintenance.

c) Successful implementation of advanced concepts requires both useful technology available in appropriate form and users that are interested and anxious to take advantage of technological opportunities. It is important in early stages to encourage applications that are manageable and have high potential for success. A commitment to the service attitude and genuine interest in solving the users specific problems are basic. A series of do's and do not's with supporting explanation follows which attempts to define a framework and strategy for software implementation.

* <u>Management should not "require" programs/concepts to be used before considerable experience and shake down is accomplished</u>. Nothing kills new technology like forced use that does not deliver the solution to everyone's problems. No new technology can be so tightly developed that it can survive an environment wherein the potential users are already somewhat negative by the forced approach. A pragmatic, steady gradual introduction will likely result in early, meaningful use of the concepts and techniques. NOTHING DRAWS USERS LIKE SUCCESS, NO MATTER HOW SMALL.

* <u>Avoid (if possible) the grand "demonstration" exercise</u>. Demonstrations that are designed to sell technology often get too many people involved (usually promoter types) so that the exercise becomes so important that the outcome ends up either being rigged or fails because of the weight of so many observers. Dissemination of basic information and publicizing applications is a valid approach, and provides the opportunity to learn and pursue the shake down process described above. Incorporation of sessions in seminars, general meetings or courses that cause people to work with the technology provides an excellent vehicle for spreading the word.

* <u>Work WITH users to solve their studies</u>. A full commitment to solving the users specific problem in a field study environment is perhaps the single most important facet of successful technology transfer. In a conceptual sense, an approach to developing advance technology that seeks to solve specific problems in a real world setting from which the general elements are merged into a continuously growing general analytical system can be more responsive to user needs than an approach that sets about creating the grand solution and then attempts to adapt it to the problems. It is important to recognize that it is an unusual application that does not have some unique aspects. It is strongly suggested that early implementation efforts be directed toward work <u>with</u> users on specific studies.

* <u>Carefully select manageable studies or portions of studies for initial applications</u>. This is the operational implementation of the

idea that nothing draws users like success, no matter how small. The careful selection of small (in scope) well-defined problems that provide the opportunity for both developers and users to learn and improve the utility of the programs is important. It should go without saying that a poor strategy is to attempt to "solve the unsolvable" as the early application of the technology. Ample opportunity to work on difficult problems (we all have an abundance of these) will be present at any point in time; build some experience base to operate from before "going for broke." A series of small, growing to more comprehensive and difficult applications over time is the desirable strategy for which to strive.

* Be prepared and willing to perform logic and program code changes as a normal part of virtually all early studies. It would be somewhat miraculous if developers of a system of programs could have foreseen all the potential study environments, objectives, data availability, issues, etc. that the techniques will be used for. Errors will exist; Murphy's Law operates in computer programs even better than in complex machinery. The attitude and ready resources to make the necessary adjustments will reflect the commitment to a "services" approach to implementation.

Observations for Systems' Users

Spatial data management systems are not a magic panacea that will solve all planning and data management problems. They comprise a powerful analytical tool (and a bit of philosophy about how to do a job). Successful use, therefore, requires: a) an understanding of the underpinning philosophy, b) thorough understanding of the strengths, weaknesses, and potential of the analytical capabilities and, c) a clear perception of the applications to be made. For example: By whom? For what purpose? As a service to whom? Over what time period?

The successful system user is the person, study, institution, etc., that has been (or is) confronted with a problem, has been struggling with it for sometime and who has come to recognize that it could be at least partially dealt with by the availability of a centralized spatial data management system. The unsuccessful user (person, study, institution) has likely been introduced to the concepts and operational features of spatial data management, and is convinced that it must surely have value, especially if appropriately used by others in the organization, (e.g., management is "upgrading" methods of performing missions of the organization). With these polar positions defined, a few comments are offered below.

a) Know your problems/needs in detail prior to examining spatial data management systems. There is a significant tendency for potential users, especially those who are not highly computer oriented, to somehow end up with their problems becoming defined by the performance capabilities of a particular system. This results in a reverse approach to acquiring/developing high technology solutions to one's problems.

b) Determine how you will solve your problems (or make applications) irrespective of the capabilities of the existing systems. Spatial data management systems and their beneficial applications require considerable commitment of resources, both dollars and manpower. It behooves the potential user to make certain that these resources are effectively used to accomplish the objective that generated the search for the technology.

c) Be aware that there are very great differences between automated drafting, spatial data systems and data used primarily for mapping and statistics--what many refer to as "GIS's," and spatial data systems and data that are usable for engineering type applications. One of the more perplexing aspects of HEC's endeavors has been that of dealing with others who equate being able to reproduce a map or map feature by a computer driven device with the greater technological needs and capability of developing usable data files and analysis programs. Automated drafting systems are designed to produce drawings--not analytically usable data files. Most GIS systems focus on placing data in computer files, retrieving the data and performing simple (overlay) type analysis and producing graphics. Systems, such as HEC-SAM and ADAPT (paper by Dr. Males, W. E. Gates & Associates), have their primary focus on engineering/analytical analysis with the spatial data file as an intermediate (although critical) step in the analysis features.

d) Thoroughly investigate features and capabilities of alternative systems. Spatial data systems can come in integrated hardware-software arrangements, systems software alone, or just specific task oriented software. Important issues involved are propriety of system (license? owner user only? other?), specialized nature of hardware (availability of service, parts, etc.), software "package" (coding standards/philosophy? specialized coding languages? documentation? service? training? installation?) and compatibility with existing/future equipment/people. It should be apparent that what is right for the fellow down the block may or may not be relevant to your needs.

e) Do not expect magic. Systems are put together by people and work products are very machine performance dependent. While one should prudently seek a system that has a track record of minimum difficulties, it is best to plan for at least some difficulties and be flexible. Start up should be well planned and attended.

f) Willingly commit the personnel resources to make the system your own. Without question, the major shortcoming in the effective utilization of comprehensive data management systems has been the unwillingness of potential users to devote adequate time and energy to "own" the system in an applications sense. These systems are sufficiently sophisticated (and expensive) that continuous use and familiarty by the users will be needed to make the investment pay off.

f) Continuously ask questions of the developers/servicers, probe the limits of capabilities, and presume a normal feature of sophisticated complex systems is that they should be continually adapted and augmented over time. A system frozen in capability from installation date is one that will soon be unresponsive to needs of the users.

SUMMARY AND CONCLUSIONS

The HEC-SAM system evolved from a need within the Corps to manage spatial data in a systematic way to achieve an increased level of analysis capability for planning studies. The system includes capabilities to create and maintain spatial data files, retrieve and display file contents, and link data sets to sophisticated computer models. The system is continuing to be improved and augmented and will certainly become a more integral part of Corps' planning studies. The system is comprised of software acquired from private sources, from other governmental agencies and from in-house development efforts. Comprehensive spatial data management systems require carefully managed continuing technology development and transfer actions to benefit the users and maintain their utility over time.

ACKNOWLEDGMENTS

The HEC-SAM system is the product of ideas from many sources and work efforts by a number of individuals. The original concept for the system and supervision of its continuing development and servicing has been the responsibility of the author. Staff members at the HEC who contributed substantially include R. Pat Webb--responsible for most of the developmental work and day-to-day servicing, Shelle Barkin--data file management, Arlen Feldman--hydrologic interfaces, and Mike Burnham--source of many ideas in systems formulation. Jack Dangermond of ESRI has provided software and a continuing flow of ideas. Dr. Dick Males of W. E. Gates and Associates has provided ideas as well as continuing moral support. Corps personnel who have been closely involved in development of HEC-SAM include Lynn Lovell and Milburn Smith of the Ft. Worth District and Bob Plott, OCE Flood Plain Management. The HEC has been under the direction of Mr. Bill S. Eichert during the time when HEC-SAM was created.

REFERENCES

(1) Davis, Darryl W., June 1978 Comprehensive Flood Plain Studies Using Spatial Data Management Techniques. Water Resources Bulletin, American Water Resources Association.

(2) The Hydrologic Engineering Center, 1978. Annual Report, Davis, California.

(3) The Hydrologic Engineering Center, 1975. Phase I Oconee Basin Pilot Study--Trail Creek Test. Davis, California.

(4) Webb, R. P., and M. W. Burnham, 1976. Spatial Analysis of Nonstructural Measures. Symposium on Inland Water for Navigation, Flood Control, and Water Diversions. American Society of Civil Engineers.

(5) The Hydrologic Engineering Center, 1978. Guide Manual for the Creation of Grid Cell Data Banks. Davis, California.

(6) U.S. Army Engineer District, Savannah, 1977. Phase I, Oconee Basin Expanded Flood Plain Information Study.

(7) U.S. Army Engineer District, Fort Worth, 1978. Rowlett Creek Expanded Flood Plain Information Study.

(8) U.S. Army Engineer District, Jacksonville, 1979. Boggy Creek Expanded Flood Plain Information Study.

Technical Paper Series

TP-1	Use of Interrelated Records to Simulate Streamflow
TP-2	Optimization Techniques for Hydrologic Engineering
TP-3	Methods of Determination of Safe Yield and Compensation Water from Storage Reservoirs
TP-4	Functional Evaluation of a Water Resources System
TP-5	Streamflow Synthesis for Ungaged Rivers
TP-6	Simulation of Daily Streamflow
TP-7	Pilot Study for Storage Requirements for Low Flow Augmentation
TP-8	Worth of Streamflow Data for Project Design - A Pilot Study
TP-9	Economic Evaluation of Reservoir System Accomplishments
TP-10	Hydrologic Simulation in Water-Yield Analysis
TP-11	Survey of Programs for Water Surface Profiles
TP-12	Hypothetical Flood Computation for a Stream System
TP-13	Maximum Utilization of Scarce Data in Hydrologic Design
TP-14	Techniques for Evaluating Long-Tem Reservoir Yields
TP-15	Hydrostatistics - Principles of Application
TP-16	A Hydrologic Water Resource System Modeling Techniques
TP-17	Hydrologic Engineering Techniques for Regional Water Resources Planning
TP-18	Estimating Monthly Streamflows Within a Region
TP-19	Suspended Sediment Discharge in Streams
TP-20	Computer Determination of Flow Through Bridges
TP-21	An Approach to Reservoir Temperature Analysis
TP-22	A Finite Difference Methods of Analyzing Liquid Flow in Variably Saturated Porous Media
TP-23	Uses of Simulation in River Basin Planning
TP-24	Hydroelectric Power Analysis in Reservoir Systems
TP-25	Status of Water Resource System Analysis
TP-26	System Relationships for Panama Canal Water Supply
TP-27	System Analysis of the Panama Canal Water Supply
TP-28	Digital Simulation of an Existing Water Resources System
TP-29	Computer Application in Continuing Education
TP-30	Drought Severity and Water Supply Dependability
TP-31	Development of System Operation Rules for an Existing System by Simulation
TP-32	Alternative Approaches to Water Resources System Simulation
TP-33	System Simulation of Integrated Use of Hydroelectric and Thermal Power Generation
TP-34	Optimizing flood Control Allocation for a Multipurpose Reservoir
TP-35	Computer Models for Rainfall-Runoff and River Hydraulic Analysis
TP-36	Evaluation of Drought Effects at Lake Atitlan
TP-37	Downstream Effects of the Levee Overtopping at Wilkes-Barre, PA, During Tropical Storm Agnes
TP-38	Water Quality Evaluation of Aquatic Systems
TP-39	A Method for Analyzing Effects of Dam Failures in Design Studies
TP-40	Storm Drainage and Urban Region Flood Control Planning
TP-41	HEC-5C, A Simulation Model for System Formulation and Evaluation
TP-42	Optimal Sizing of Urban Flood Control Systems
TP-43	Hydrologic and Economic Simulation of Flood Control Aspects of Water Resources Systems
TP-44	Sizing Flood Control Reservoir Systems by System Analysis
TP-45	Techniques for Real-Time Operation of Flood Control Reservoirs in the Merrimack River Basin
TP-46	Spatial Data Analysis of Nonstructural Measures
TP-47	Comprehensive Flood Plain Studies Using Spatial Data Management Techniques
TP-48	Direct Runoff Hydrograph Parameters Versus Urbanization
TP-49	Experience of HEC in Disseminating Information on Hydrological Models
TP-50	Effects of Dam Removal: An Approach to Sedimentation
TP-51	Design of Flood Control Improvements by Systems Analysis: A Case Study
TP-52	Potential Use of Digital Computer Ground Water Models
TP-53	Development of Generalized Free Surface Flow Models Using Finite Element Techniques
TP-54	Adjustment of Peak Discharge Rates for Urbanization
TP-55	The Development and Servicing of Spatial Data Management Techniques in the Corps of Engineers
TP-56	Experiences of the Hydrologic Engineering Center in Maintaining Widely Used Hydrologic and Water Resource Computer Models
TP-57	Flood Damage Assessments Using Spatial Data Management Techniques
TP-58	A Model for Evaluating Runoff-Quality in Metropolitan Master Planning
TP-59	Testing of Several Runoff Models on an Urban Watershed
TP-60	Operational Simulation of a Reservoir System with Pumped Storage
TP-61	Technical Factors in Small Hydropower Planning
TP-62	Flood Hydrograph and Peak Flow Frequency Analysis
TP-63	HEC Contribution to Reservoir System Operation
TP-64	Determining Peak-Discharge Frequencies in an Urbanizing Watershed: A Case Study
TP-65	Feasibility Analysis in Small Hydropower Planning
TP-66	Reservoir Storage Determination by Computer Simulation of Flood Control and Conservation Systems
TP-67	Hydrologic Land Use Classification Using LANDSAT
TP-68	Interactive Nonstructural Flood-Control Planning
TP-69	Critical Water Surface by Minimum Specific Energy Using the Parabolic Method

TP-70 Corps of Engineers Experience with Automatic Calibration of a Precipitation-Runoff Model
TP-71 Determination of Land Use from Satellite Imagery for Input to Hydrologic Models
TP-72 Application of the Finite Element Method to Vertically Stratified Hydrodynamic Flow and Water Quality
TP-73 Flood Mitigation Planning Using HEC-SAM
TP-74 Hydrographs by Single Linear Reservoir Model
TP-75 HEC Activities in Reservoir Analysis
TP-76 Institutional Support of Water Resource Models
TP-77 Investigation of Soil Conservation Service Urban Hydrology Techniques
TP-78 Potential for Increasing the Output of Existing Hydroelectric Plants
TP-79 Potential Energy and Capacity Gains from Flood Control Storage Reallocation at Existing U.S. Hydropower Reservoirs
TP-80 Use of Non-Sequential Techniques in the Analysis of Power Potential at Storage Projects
TP-81 Data Management Systems of Water Resources Planning
TP-82 The New HEC-1 Flood Hydrograph Package
TP-83 River and Reservoir Systems Water Quality Modeling Capability
TP-84 Generalized Real-Time Flood Control System Model
TP-85 Operation Policy Analysis: Sam Rayburn Reservoir
TP-86 Training the Practitioner: The Hydrologic Engineering Center Program
TP-87 Documentation Needs for Water Resources Models
TP-88 Reservoir System Regulation for Water Quality Control
TP-89 A Software System to Aid in Making Real-Time Water Control Decisions
TP-90 Calibration, Verification and Application of a Two-Dimensional Flow Model
TP-91 HEC Software Development and Support
TP-92 Hydrologic Engineering Center Planning Models
TP-93 Flood Routing Through a Flat, Complex Flood Plain Using a One-Dimensional Unsteady Flow Computer Program
TP-94 Dredged-Material Disposal Management Model
TP-95 Infiltration and Soil Moisture Redistribution in HEC-1
TP-96 The Hydrologic Engineering Center Experience in Nonstructural Planning
TP-97 Prediction of the Effects of a Flood Control Project on a Meandering Stream
TP-98 Evolution in Computer Programs Causes Evolution in Training Needs: The Hydrologic Engineering Center Experience
TP-99 Reservoir System Analysis for Water Quality
TP-100 Probable Maximum Flood Estimation - Eastern United States
TP-101 Use of Computer Program HEC-5 for Water Supply Analysis
TP-102 Role of Calibration in the Application of HEC-6
TP-103 Engineering and Economic Considerations in Formulating
TP-104 Modeling Water Resources Systems for Water Quality
TP-105 Use of a Two-Dimensional Flow Model to Quantify Aquatic Habitat
TP-106 Flood-Runoff Forecasting with HEC-1F
TP-107 Dredged-Material Disposal System Capacity Expansion
TP-108 Role of Small Computers in Two-Dimensional Flow Modeling
TP-109 One-Dimensional Model for Mud Flows
TP-110 Subdivision Froude Number
TP-111 HEC-5Q: System Water Quality Modeling
TP-112 New Developments in HEC Programs for Flood Control
TP-113 Modeling and Managing Water Resource Systems for Water Quality
TP-114 Accuracy of Computer Water Surface Profiles - Executive Summary
TP-115 Application of Spatial-Data Management Techniques in Corps Planning
TP-116 The HEC's Activities in Watershed Modeling
TP-117 HEC-1 and HEC-2 Applications on the Microcomputer
TP-118 Real-Time Snow Simulation Model for the Monongahela River Basin
TP-119 Multi-Purpose, Multi-Reservoir Simulation on a PC
TP-120 Technology Transfer of Corps' Hydrologic Models
TP-121 Development, Calibration and Application of Runoff Forecasting Models for the Allegheny River Basin
TP-122 The Estimation of Rainfall for Flood Forecasting Using Radar and Rain Gage Data
TP-123 Developing and Managing a Comprehensive Reservoir Analysis Model
TP-124 Review of U.S. Army corps of Engineering Involvement With Alluvial Fan Flooding Problems
TP-125 An Integrated Software Package for Flood Damage Analysis
TP-126 The Value and Depreciation of Existing Facilities: The Case of Reservoirs
TP-127 Floodplain-Management Plan Enumeration
TP-128 Two-Dimensional Floodplain Modeling
TP-129 Status and New Capabilities of Computer Program HEC-6: "Scour and Deposition in Rivers and Reservoirs"
TP-130 Estimating Sediment Delivery and Yield on Alluvial Fans
TP-131 Hydrologic Aspects of Flood Warning - Preparedness Programs
TP-132 Twenty-five Years of Developing, Distributing, and Supporting Hydrologic Engineering Computer Programs
TP-133 Predicting Deposition Patterns in Small Basins
TP-134 Annual Extreme Lake Elevations by Total Probability Theorem
TP-135 A Muskingum-Cunge Channel Flow Routing Method for Drainage Networks
TP-136 Prescriptive Reservoir System Analysis Model - Missouri River System Application
TP-137 A Generalized Simulation Model for Reservoir System Analysis
TP-138 The HEC NexGen Software Development Project
TP-139 Issues for Applications Developers
TP-140 HEC-2 Water Surface Profiles Program
TP-141 HEC Models for Urban Hydrologic Analysis

TP-142 Systems Analysis Applications at the Hydrologic Engineering Center
TP-143 Runoff Prediction Uncertainty for Ungauged Agricultural Watersheds
TP-144 Review of GIS Applications in Hydrologic Modeling
TP-145 Application of Rainfall-Runoff Simulation for Flood Forecasting
TP-146 Application of the HEC Prescriptive Reservoir Model in the Columbia River Systems
TP-147 HEC River Analysis System (HEC-RAS)
TP-148 HEC-6: Reservoir Sediment Control Applications
TP-149 The Hydrologic Modeling System (HEC-HMS): Design and Development Issues
TP-150 The HEC Hydrologic Modeling System
TP-151 Bridge Hydraulic Analysis with HEC-RAS
TP-152 Use of Land Surface Erosion Techniques with Stream Channel Sediment Models
TP-153 Risk-Based Analysis for Corps Flood Project Studies - A Status Report
TP-154 Modeling Water-Resource Systems for Water Quality Management
TP-155 Runoff simulation Using Radar Rainfall Data
TP-156 Status of HEC Next Generation Software Development
TP-157 Unsteady Flow Model for Forecasting Missouri and Mississippi Rivers
TP-158 Corps Water Management System (CWMS)
TP-159 Some History and Hydrology of the Panama Canal
TP-160 Application of Risk-Based Analysis to Planning Reservoir and Levee Flood Damage Reduction Systems
TP-161 Corps Water Management System - Capabilities and Implementation Status